Real-Life Observations of Power System Dynamic Phenomena

Some Interesting Aspects

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The Indian Grid

Installed Capacity: ~ 180 GW
By 2027: ~575 GW

<table>
<thead>
<tr>
<th>Energy Source</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal</td>
<td>65%</td>
</tr>
<tr>
<td>Hydro</td>
<td>21%</td>
</tr>
<tr>
<td>Nuclear</td>
<td>3%</td>
</tr>
<tr>
<td>Renewable</td>
<td>11%</td>
</tr>
</tbody>
</table>

Renewables: Wind, Small Hydro, Biomass etc

Wind Energy: 14 GW (Fifth Largest)

~2014 one synchronous grid

Courtesy: Power Grid Corporation of India Ltd. / Ministry of Power
The Indian Grid

Energy Resources

Major Load Centres

Hydro

Thermal

 Courtesy: Power Grid Corporation of India Ltd. / Ministry of Power
The Indian Grid: HVDC/FACTS

- 765 kV
- 2 d/c 400 kV AC lines with TCSCs
- 1 transmission line SVC
- Several Series Compensated lines
- WAMS: Pilot project
Changing Load Characteristics

Source: CEA General Review 2006

Silicon Loads  Future Load Curve?
Overview

• Real-Life Observations in the Indian Grid
  - Small Signal Instabilities
  - Propagation Delay of Electro-Mechanical Transients
  - Generator Tripping Events: System Inertia

Sources of these Observations:
1. NTP-synchronized wide-area frequency measurement system (IITB)
2. PSS Tuning Exercise (IITB/WRPC/BHEL)
3. Disturbance Reports (WRPC/MSTECL)
4. Published Literature
Wide Area Frequency Measurement

Network Time Protocol based
~15 ms synchronization error

FNET USA (GPS based)
WAFM Locations

~ 1500 km
Wide Area, Electro-mechanical Phenomena

- Sudden Load Throw Off
  - Stable Common and Relative Motion

- Sudden Generation Trip
  - Stable Common and Relative Motion

- Large Disturbance Angular Instability: Loss of Synchronism

- Small Disturbance Angular Instability: Growing Oscillations
  (triggered by any disturbance: big or small)
Observation I: Propagation Delay

Legend
- Mumbai
- Kanpur
- Kharagpur
- Ahmedabad
- Indore
- TEST

Y-axis: Frequency ---->

INDIA

Mumbai

Ahmedabad

Indore

Kanpur

Kharagpur

49.7

49.6

X-axis: time ---->
Observation I: Propagation Delay
Observation I: Propagation Delay
Lumped/Distributed Parameter Models – Electro-magnetic
Lumped/Distributed Parameter Models – Electro-mechanical


- Electro-mechanical Analogy: Mass-Spring System

- A large system with spread-out generators and lines ~ like a distributed parameter mass-spring system!
  \[ \sim 1500 \text{ km/s} \]
Unstable Intra-Plant Swings

PSS Tuning at 210 MW Satpura (India) – PSS polarity incorrect
Local and Inter-area Swings

- A Stable Swing
Local and Inter-area Swings

• Sustained Swing
Two Sustained Local and Inter-area Swings (Limit Cycle ?)
Non-linear behaviour

Out of step

Small Signal Unstable

Sustained oscillation (stable limit cycle)

\[ \omega_n = 2 \times \pi \times 1 \text{ rad/s}, \quad \xi = 0.01 \]

Small Signal **Stable** (poorly damped) excited by noise
Oscillations in the WSCC System, August 1996

John Hauer, Dan Trudnowski, Graham Rogers, Bill Mittelstadt Wayne Litzenberger, Jeff Johnson,
Loss of Synchronism / Out of Step Operation – Idealized Scenario

Not Acceptable!
Distance Relays trip

Uncontrolled
System Separation
Laboratory Observation

Instantaneous Currents in Amperes

Instantaneous Voltage ($V_a$) in Volts

RMS Current ($I_a$) in Amperes & Scaled RMS Voltage and Field Current ($I_f$)

Time in Seconds

Courtesy:
Dr K.N. Shubhanga
System Separation: Typical Cut Set

POWER MAP OF WESTERN REGION
AS ON 20.10.2003

GUJARAT
1. Ahwa
2. Zadadla
3. Kim
4. Ramesan
5. Kapanwadi
6. Mangrol
(Surat LPP)

MAHARASHTRA
1. Japi
2. Theur
3. Panvati

MADHYA PRADESH

RAJASTHAN

Uncontrolled separation

Controlled Islanding (Mumbai)

Uncontrolled separation
Large Power Swing / Loss of Synchronism

Courtesy:
Western Regional Power Committee, Mumbai
~1800 MW Generator Tripping

DATE: 8th Oct 2009
Start Time: 10:24:56
End Time: 10:44:56

GEN TRIP AT 10:29:15

Underfrequency Relays operate
DATE: 8th Oct 2009
Start Time: 10:29:06
End Time: 10:30:06

GEN TRIP AT 10:29:15

EXPANDED VIEW

ANOTHER GEN TRIP AT 10:29:30

Minor swings (period 2-3 s)

Load Relief
How can WAMS help?

- **Frequency Control:**
  - Under Frequency Relaying:
    Local frequency contaminated due to swings (1-2 Hz).
    $df/dt$ should not trigger on swings but on "common" motion.

**Solution:** *filter*, but filtering will involve delay.

- Rate of Change of *Center of Inertia* Speed (NOT LOCAL)
- Reflects actual power deficiency.
  **Need to know total inertia** (will need to know whether islanded or not, which generators in island)
Inertia Estimates

\[
\frac{2H}{\omega_B} \frac{d\omega_{COI}}{dt} \approx \Sigma P_m - \Sigma P_L - \text{losses}
\]

\[
H = \Sigma H_i \\
\omega_{COI} = \frac{\Sigma H_i \omega_i}{\Sigma H_i}
\]

Expected (adding up H of individual generators): between 3.5 - 4 MJ/MVA

What we generally get: 5-10 MJ/MVA!

Main Sources of Error? Load Dependence on Voltage, Load Inertia

To conclude …

- The excitement of observing system-wide dynamic phenomena.

- Observations not inconsistent with theory – but some subtleties.